Electron Cooler for

Low-Energy RHIC Operation

December 17, 2009

Meeting agenda

- Aperture limitation in RHIC
- Beam pipe size in cooling section
- Discussion of baseline parameters
- Outstanding questions

Problem of over focusing from ion beam

Although, it looks like problem of secondary ions can be addressed, the problem of over focusing remains (discussed 12/03/09):

For lowest energy point:

Peak current of ions is 0.4A

Electron current: 0.05-0.1A

So, instead of defocusing in the cooling section due electron beam space charge we have focusing of electron beam by ion beam.

Such focusing is weak. But for cooling, resulting angles exceed requirement already after 4 meters of interaction.

Solution?

Back to FNAL design with solenoids?

Baseline for cooling section?

With magnetization:

Pros:

1. working approach
2. "as is" from FNAL, a lot of experience available
3. minimum modifications will be needed

Cons:

1. will require smaller beam pipe
2. some redesigning of gap between solenoids may be needed
3. looks complicated

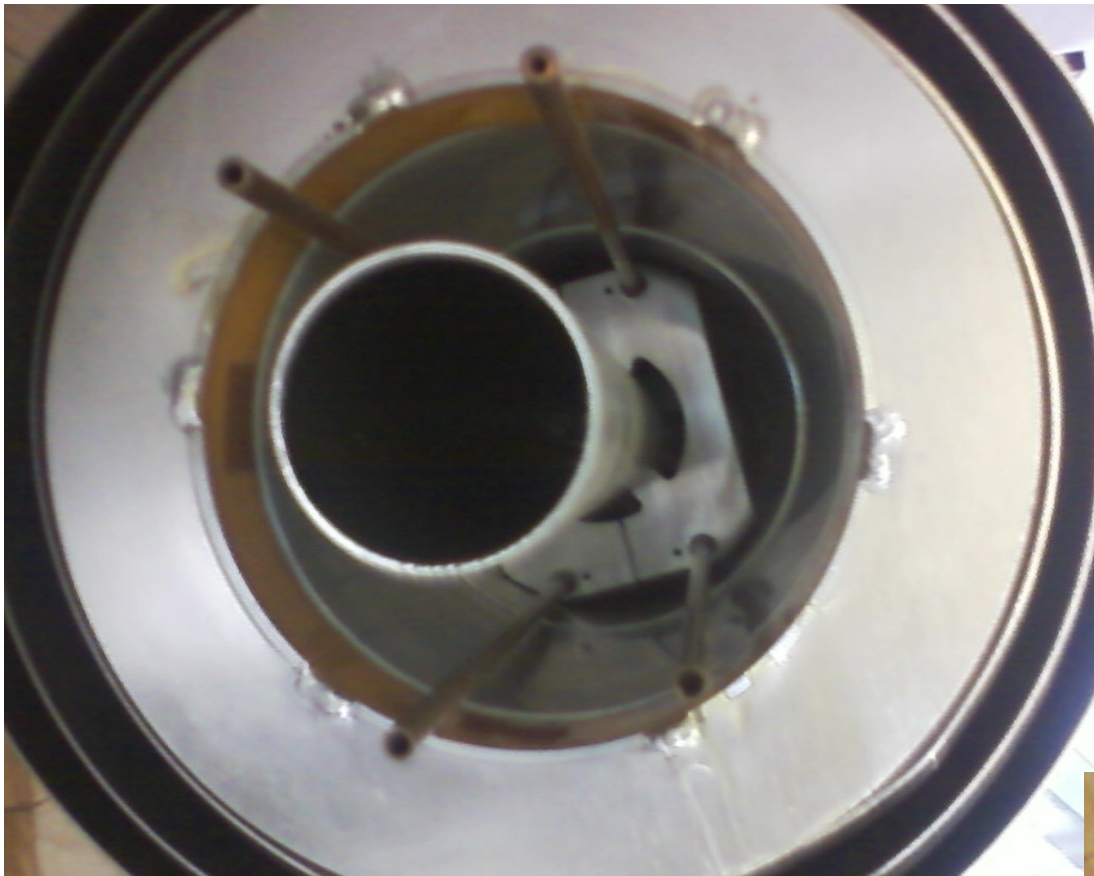
Without magnetization:

Pros:

1. looks simpler

Cons:

1. approach which was not demonstrated
2. problem of over focusing
3. will require high e-current
4. problem of recombination
5. undulator design + cost
6. significant design complications
7. problem of high-current transport through the Pelletron without magnetization



If we go with zero magnetic field approach, then we do not change present 5” beam pipe in RHIC.
But this approach requires several other questions to be addressed.

If approach with magnetic field:
What is maximum allowable pipe diameter for baking to fit into solenoids?
R_solenoid=6.9cm?
Can we do R=3.75cm (3” pipe)?
R=5cm (4” pipe)?

If we go with "solenoids" option:

1. **M. Mapes – both 3″ pipe and 4″ pipe will work for baking.**
2. **BPM's:**

- **3″ pipe (R=3.8cm) will allow BPMs to be placed between vacuum chamber and solenoids (R=6.9cm); one can use FNAL's design of BPM's; no need to modify gap between solenoids. But will need to modify RHIC lattice for cooling section significantly (from 100m to 30m beta-function).**
- **4″ pipe requires putting BPM's in the gap; requires redesigning of the gap, adding additional corrector coils.**

If we go without "solenoids" options:

- Requires solutions for control of electron angles in cooling section

Option with solenoids – 3″ pipe and aperture limitation in RHIC

@ γ=10.6 (ε=20μm)

	A_x [mm]	A_y [mm]	β_x [m]	β_y [m]	$A_x/\sqrt{\varepsilon_x \beta_x}$ [σ]	$A_y/\sqrt{\varepsilon_y \beta_y}$ [σ]
Abort kicker	25.4	38.1	45	144	6.8	5.6
Injection kickers	20.5	20.5	25	36	7.3	6.1
Triplet	65	65	170	170	8.9	8.9
E-cooler	38	38	30 100	30 100	12.4 6.8	12.4 6.8

Option with solenoids – 3″ pipe and aperture limitation in RHIC

@ γ=2.7 (ε=20μm)

	A_x [mm]	A_y [mm]	β_x [m]	β_y [m]	$A_x/\sqrt{\varepsilon_x \beta_x}$ [σ]	$A_y/\sqrt{\varepsilon_y \beta_y}$ [σ]
Abort kicker	**25.4**	**38.1**	**45**	**144**	**3.3**	**2.7**
Injection kickers	**20.5**	**20.5**	**25**	**36**	**3.9**	**2.9**
Triplet	**65**	**65**	**170**	**170**	**4.3**	**4.3**
E-cooler	**38**	**38**	**30** **50** **100**	**30** **50** **100**	**6** **4.6** **3.3**	**6** **4.6** **3.3**

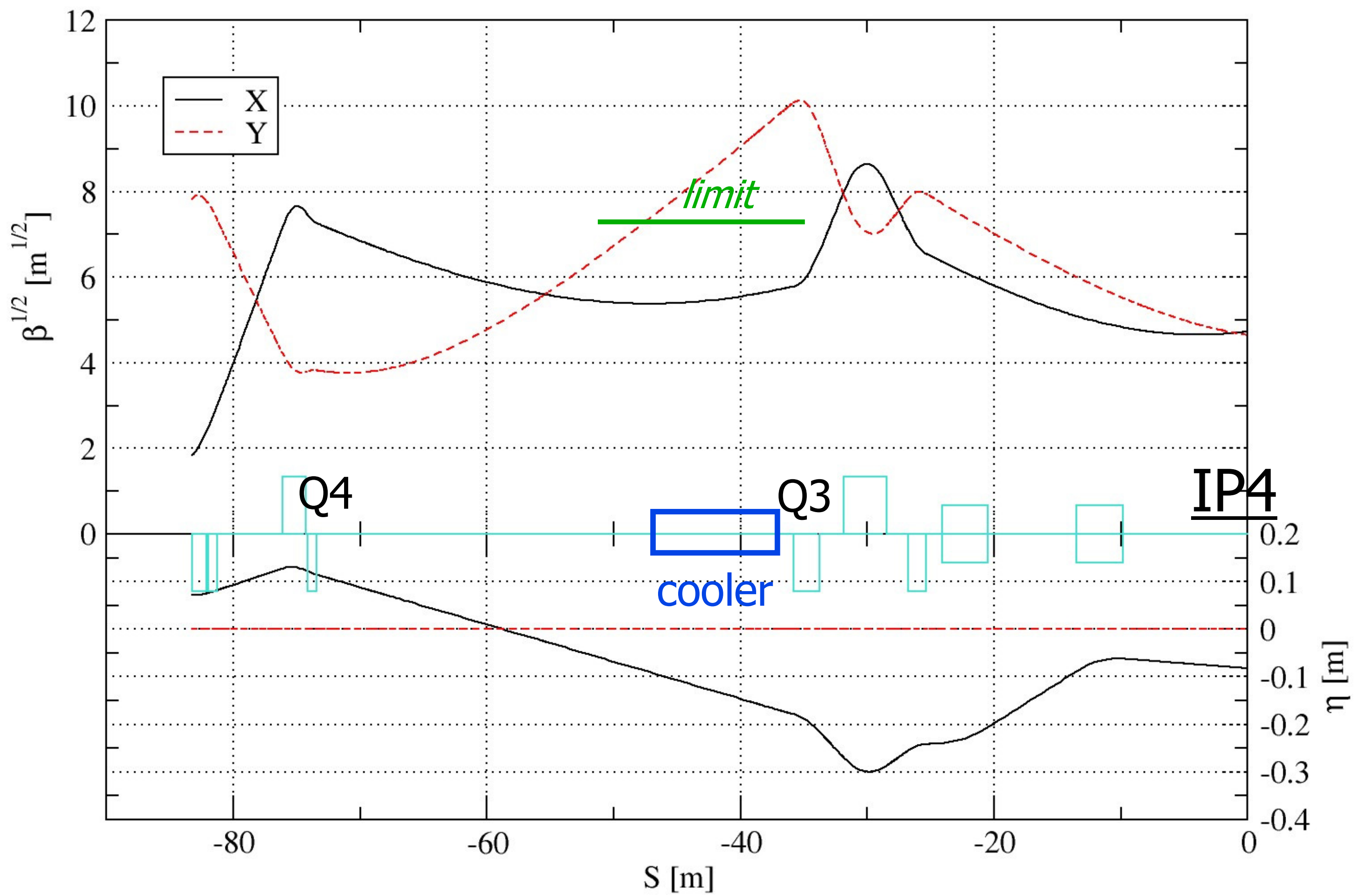
Cooling section beam-pipe

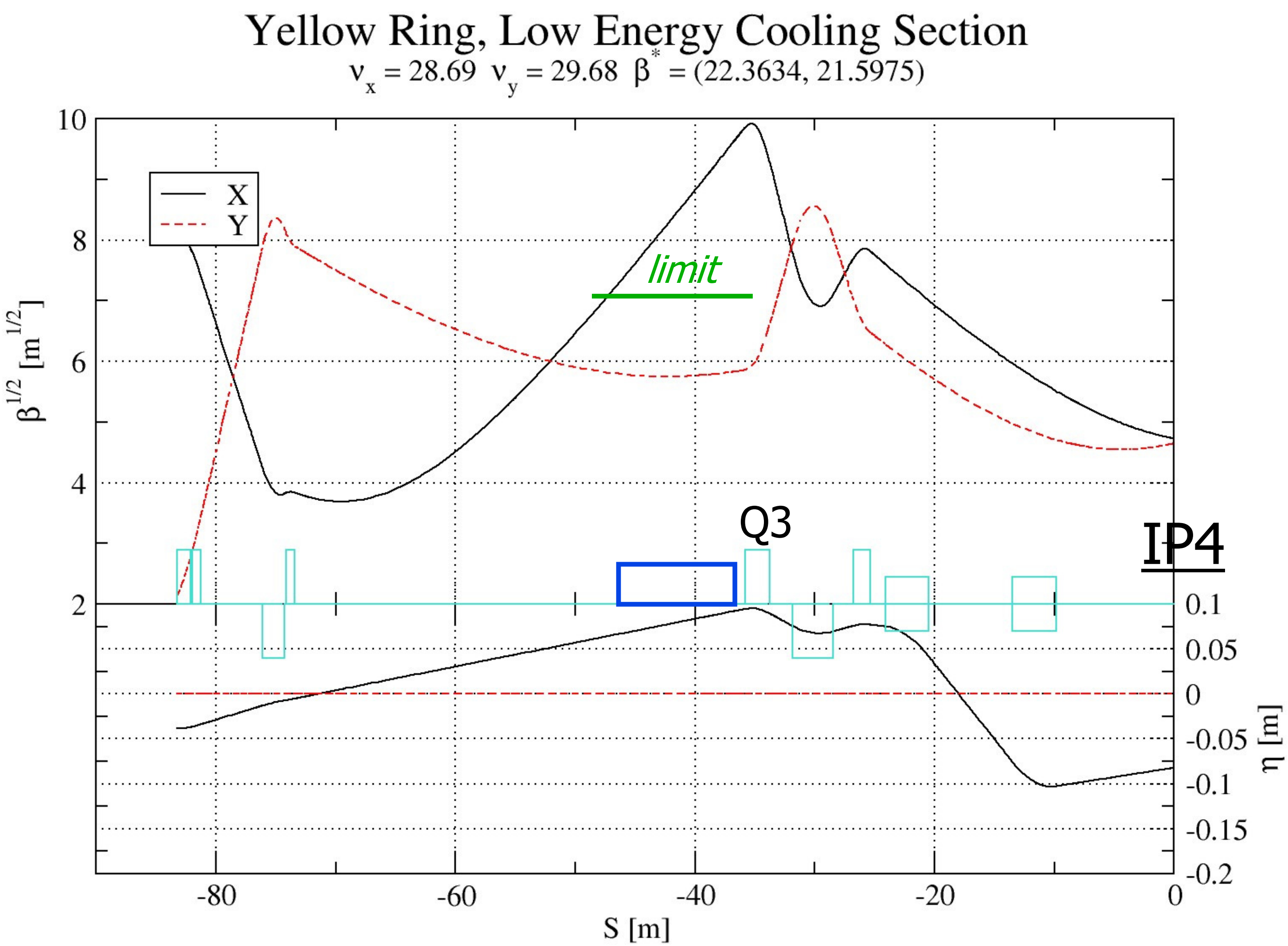
- **It looks like choosing 3″ pipe in cooling section does not cause any aperture limitation, provided that beta-functions in cooling section are chosen in the range 30-50 meters.**
- **This is at IR4 (sector 3). Warm section. Next to Q3 (2 m after Q3 and going over 10 meters).**

Steve Tepikian will need to look at RHIC lattice and see what beta-functions in cooling section are o'kay (next two slides)

Blue Ring, Low Energy Cooling Section

$\nu_x = 28.69 \quad \nu_y = 29.68 \quad \beta^* = (22.3634, 21.5975)$




Yellow Ring, Low Energy Cooling Section
ν_x = 28.69 ν_y = 29.68 β^* = (22.3634, 21.5975)
X
Y
limit
Q3
IP4
$\beta^{1/2}$ [m$^{1/2}$]
η [m]
S [m]
10
8
6
4
2
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-80
-60
-40
-20
0

Pelletron location: IR4

Option#1:

1) Steep slope

dirt will be removed to make flat road access

2) need to assemble Pelletron over the cryo lines

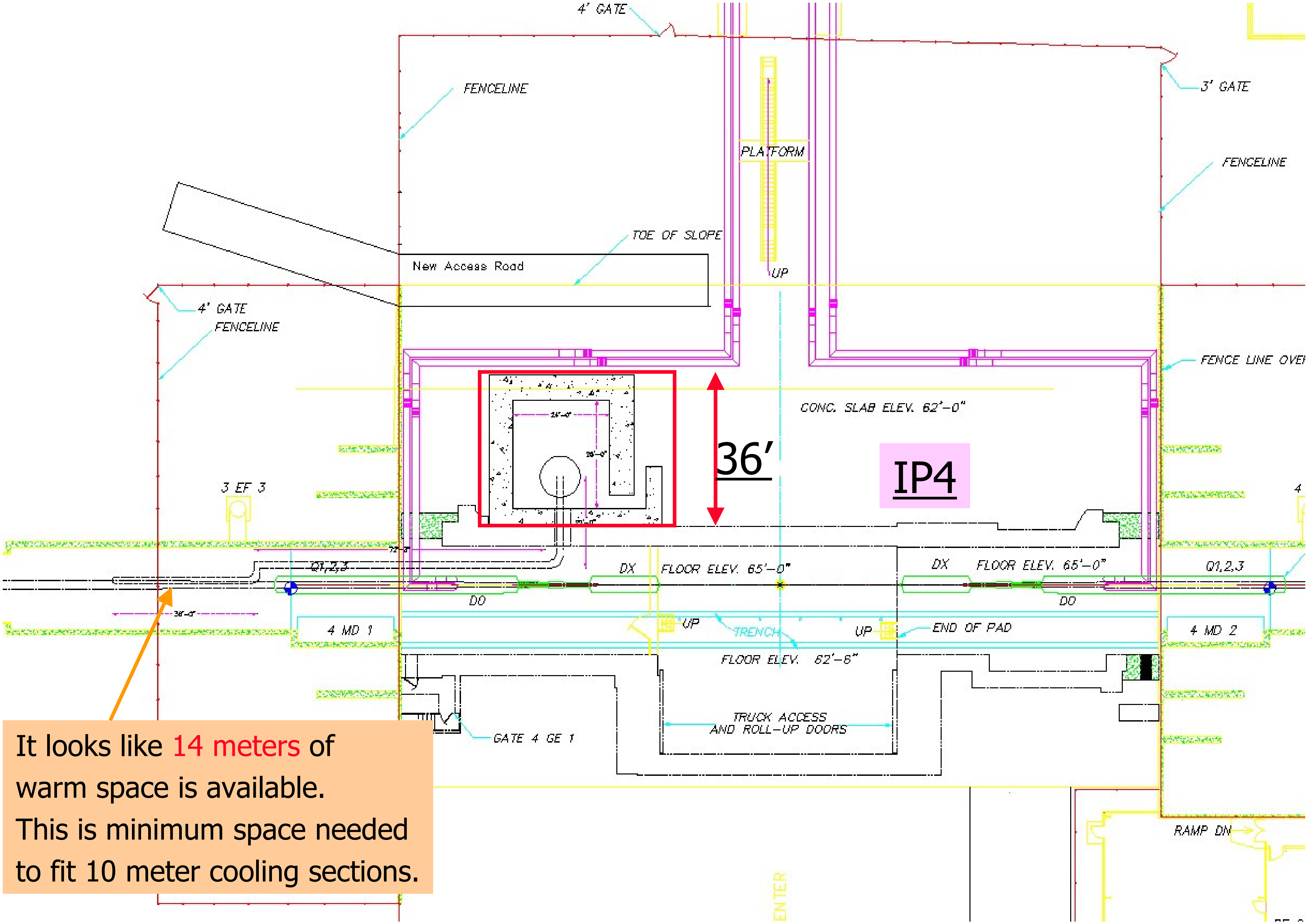
it was done before and should not be a problem

3) Building of blockhouse should be done during RHIC shutdown, since this area is behind the fence. But once Pelletron is installed one can move the fence to allow access to blockhouse during RHIC operation.

Option#2: Blockhouse can be assembled outside cryo pipes:

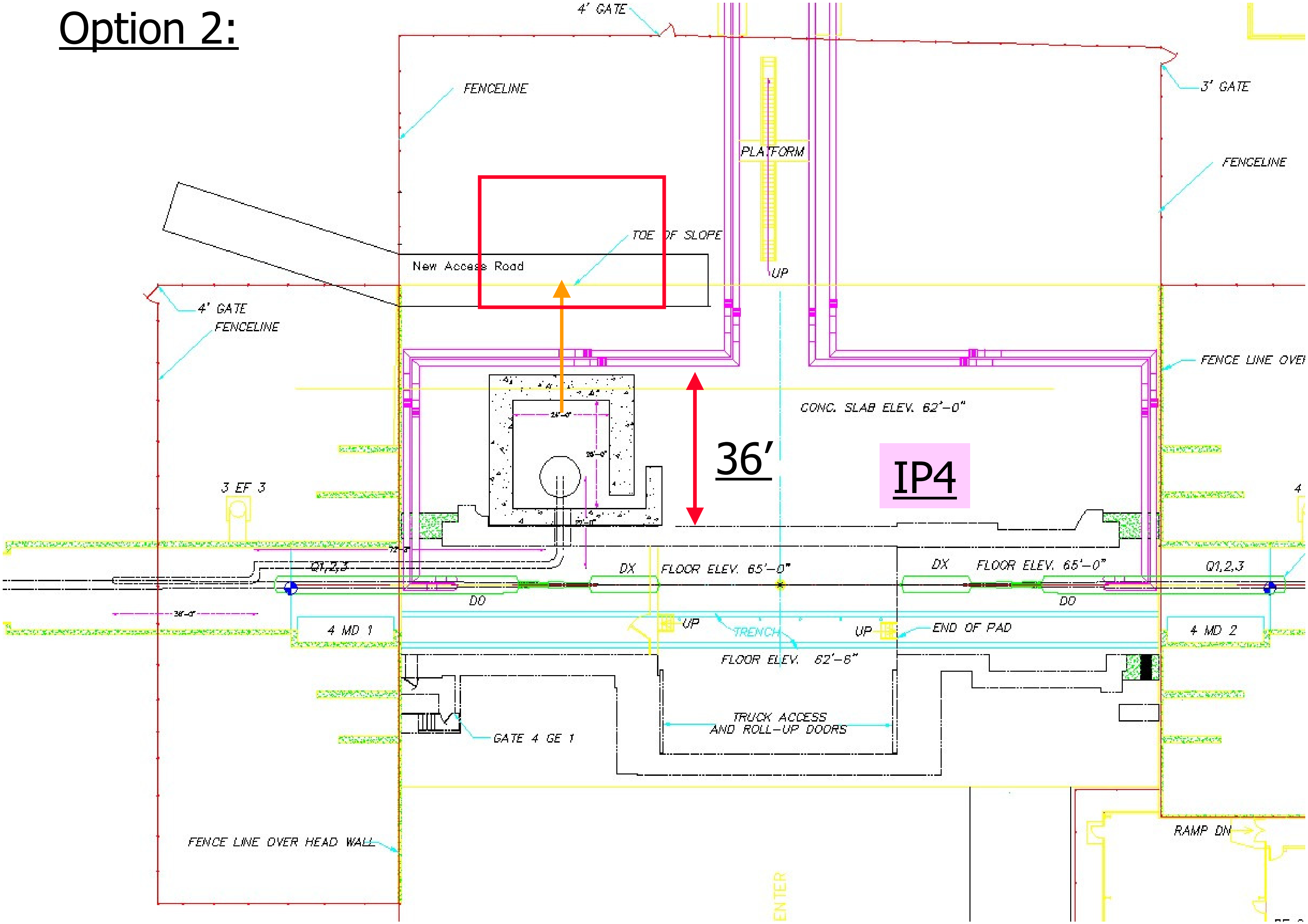
- this makes longer beam transport by 36'
- but allows assembly during RHIC operation; easier access.

- construction during RHIC operation?



It looks like 14 meters of warm space is available.
This is minimum space needed to fit 10 meter cooling sections.

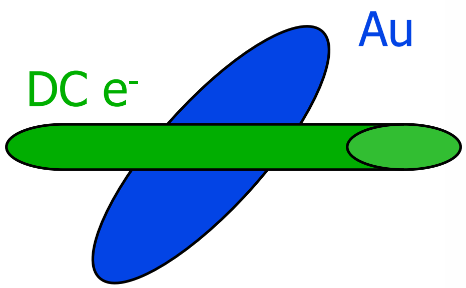
Option 2:

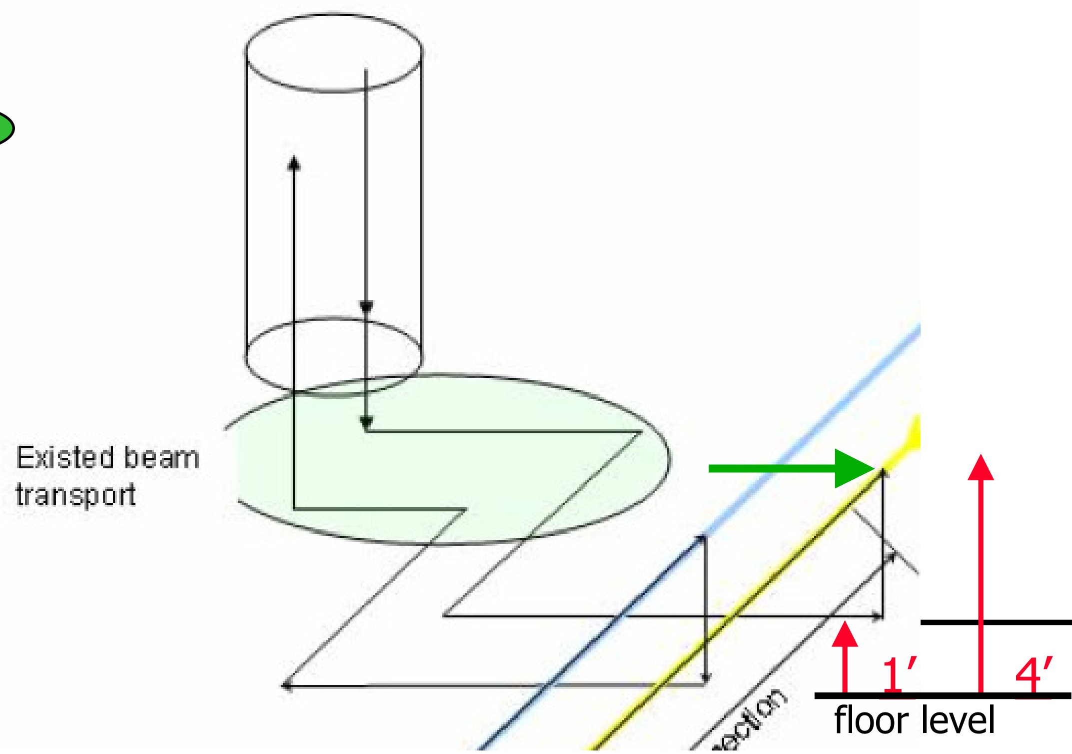


4' GATE
FENCELINE
3' GATE
PLATFORM
FENCELINE
TOE OF SLOPE
New Access Road
UP
4' GATE
FENCELINE
FENCE LINE OVEI
CONC. SLAB ELEV. 62'-0"
36'
IP4
3 EF 3
Q1,2,3
DX
FLOOR ELEV. 65'-0"
DX
FLOOR ELEV. 65'-0"
Q1,2,3
DO
DO
4 MD 1
UP
TRENCH
UP
END OF PAD
4 MD 2
FLOOR ELEV. 62'-6"
TRUCK ACCESS
AND ROLL-UP DOORS
GATE 4 GE 1
FENCE LINE OVER HEAD WALL
RAMP DN
ENTER

Minimizing number of bends

- **Presently, the plan is to go with DC electron beam around one ion beam pipe to inject into the other.**
- **Can we consider going right through the ion beam?**





Electron DC beam going through ion bunches

- **The effect was estimated as beam-beam at 90 degree angle.**
- **It looks like no effect on horizontal motion. There is an effect on vertical motion of ions but it is negligible (see next slide).**

Should we adopt as baseline approach?:

Coming with e-beam directly at the level of RHIC beams: 4′ from floor level?

Going through the ion beam with 90 degree angles?

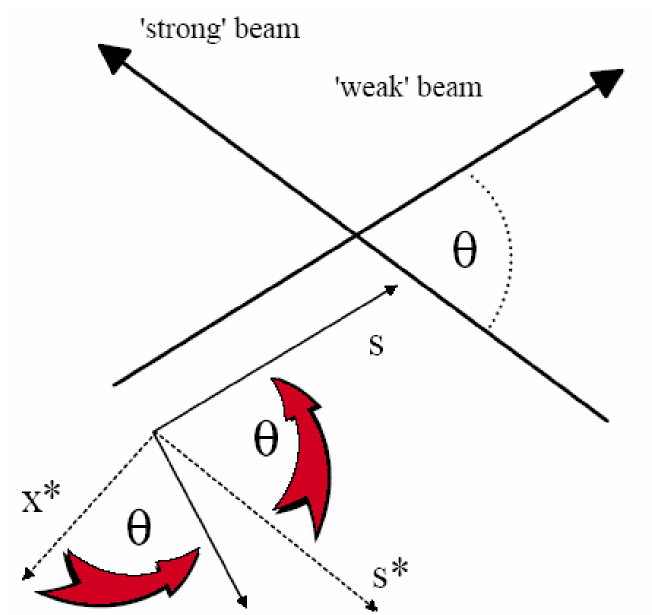
Going through with a smaller angle (add negligible horizontal tune shift)?

Tune shift on
ion beam due to 10m
co-propagated e-beam

$L_s = 10\,\mathrm{m}$ $\beta ic = 30\,\mathrm{m}$

$$\Delta\nu_{ie} := \frac{Z}{A}\cdot\frac{n_{eL}\cdot r_p}{2\cdot beta^2\gamma^3}\cdot L_s\cdot\beta ic$$

$$\Delta\nu_{ie} = 2.419\times 10^{-5}$$



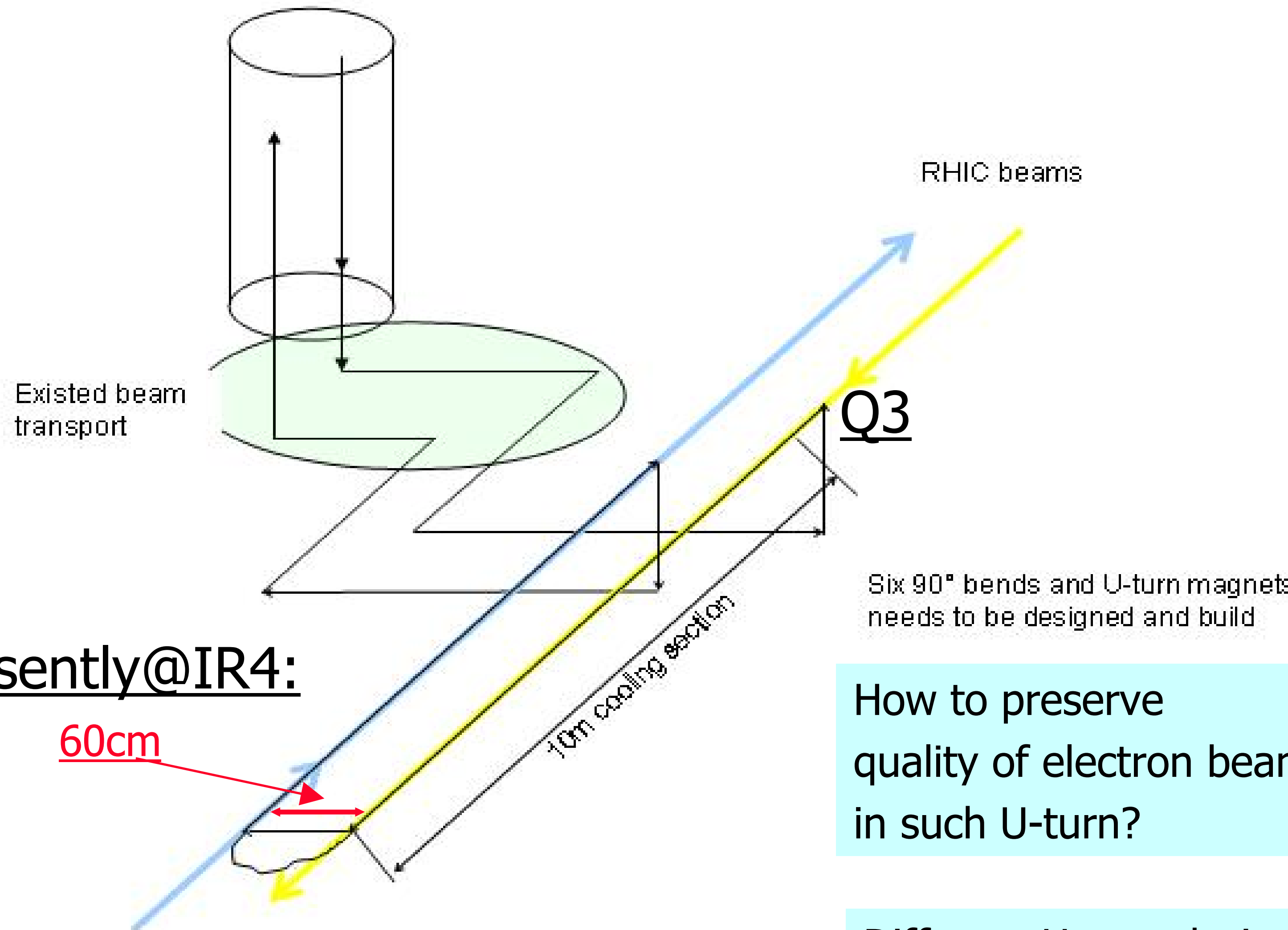
F. Ruggiero and F. Zimmermann

$$\begin{aligned}\Delta Q_x &= +\frac{\lambda r_p \beta^*}{\pi\gamma}\left(\frac{1+\cos\theta}{2}\right)\cos\theta \int_{-l/2}^{l/2}\left(1+\frac{s^2}{\beta^{*2}}\right)\\ &\times\left\{\frac{1}{s^2\sin^2\theta}\left[1-\exp\left(-\frac{s^2\sin^2\theta}{2\sigma^2}\right)\right]\right.\\ &\left.-\exp\left(-\frac{s^2\sin^2\theta}{2\sigma^2}\right)\frac{1}{\sigma^2}\right\}ds\,, \qquad (13)\\ \Delta Q_y &= -\frac{\lambda r_p \beta^*}{\pi\gamma}\left(\frac{1+\cos\theta}{2}\right)\int_{-l/2}^{l/2}\left(1+\frac{s^2}{\beta^{*2}}\right)\\ &\times\left\{\frac{1}{s^2\sin^2\theta}\left[1-\exp\left(-\frac{s^2\sin^2\theta}{2\sigma^2}\right)\right]\right\}ds\,,\end{aligned}$$

<u>Of the order of 10^{-7} vertical tune shift</u>

Baseline parameters

1. FNAL's cooling section "as is" – with solenoids, correctors, etc.
2. Cooling section beam pipe size – 3" ID.
3. BPM's design for 3" pipe – using FNAL's design?
4. Going with electron beam straight through the ion beam at the elevation level of RHIC beams (4' from floor).
5. Blockhouse @ IR4: inside or outside cryo-lines?



Presently@IR4:

How to preserve quality of electron beam in such U-turn?

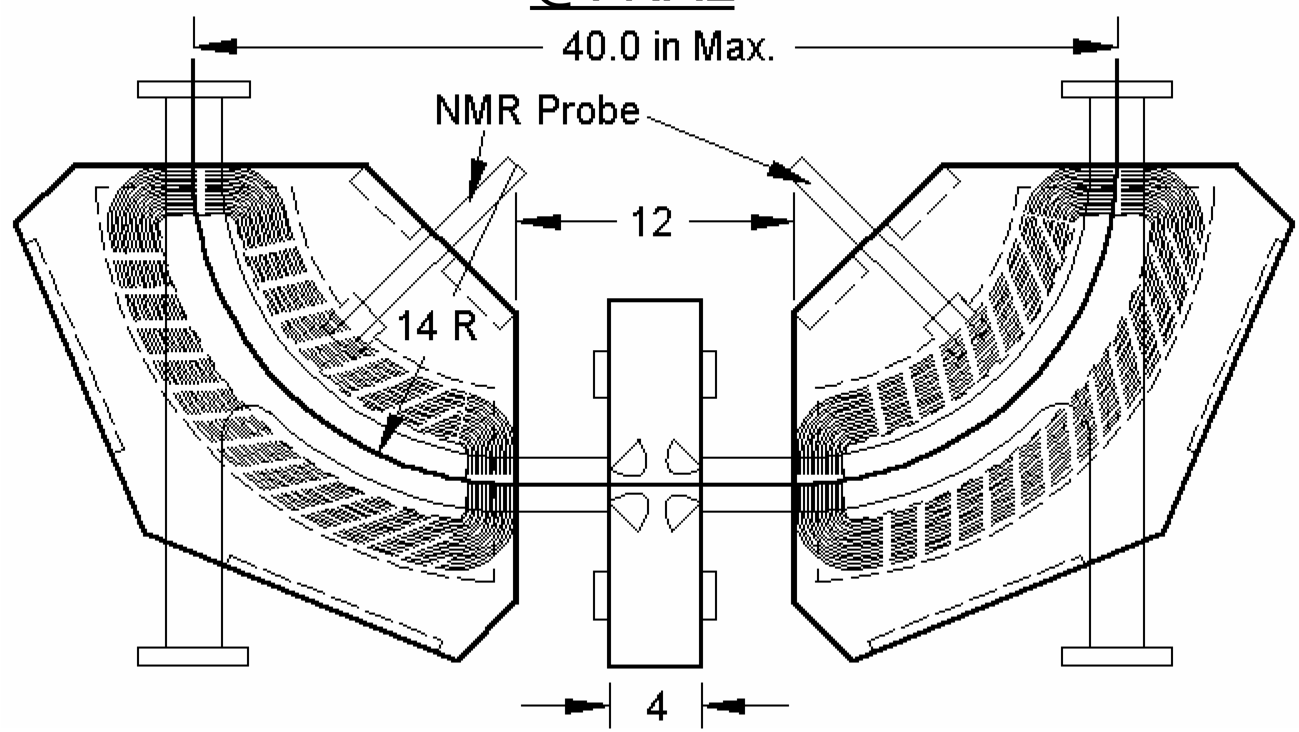
Different U-turn design?

U-bend at FNAL

@IR4: 24in (Preliminary design D.Kayran, J.Brodowski)

@IR12: 28in

@FNAL



Some physics questions

Besides some technical modifications, this will be the first cooler to cool directly beams under collisions (many interesting consequences).

1. Quality of electron beam transport at lowest energies. Design of 90 degree bends for full energy range (0.9-5MeV).
2. Special consideration for turn around (U-turn) of electron beam between cooling section.
3. Estimates of various contributions to angular budget in cooling section in all energy range of interest.
4. Requirement on energy control in both RHIC rings.
5. Requirement of beam alignment in all energy range.
6. Do we need undulators for recombination suppression?
7. Maximum size of electron beam in cooling section? Cooling with large electron beam on center or small beam off-center?
8. Simulations. Gun and Pelletron: SAM/UltraSAM (used at FNAL); TRAK (used at BNL). PARMELA or OPTIM for cooler optics and matching,

Some engineering questions

1. Can we use Recycler magnets from 90 degree bends? Quality of field at low energies is an issue.
2. Can we use Recycler's feedback system based on NMR or the field is too low for NMR?
3. Is present 180 ("U-turn") degree turn satisfactory for preserving quality of electron beam from one section to another?
4. Design of undulator for recombination suppression.
5. What engineering modifications to present cooling sections are needed to accommodate undulators?
6. Is required vacuum chamber size in cooling section compatible with present design of cooling section with many things located in between vacuum chamber and solenoids? Issue: vacuum chamber needs to be increase due to large ion beam size at low energy which reduces the space to the inner board of the solenoids – under study

Major "near-term" tasks

1. Transport of electron beam at lower energies; design of bending magnets; evaluating needed control of field quality.
2. Design of turn around (U-turn) of electron beam between cooling sections. Checking preservation of electron beam quality with additional bends, lowest energy, etc.
3. Electron cooler optics. Electron beam.
4. Ion beam optics for cooling section.
5. Careful consideration of "angular budget" in the cooling section from various effects in full energy range of interest – to be presented
6. Interaction of electron and ion beams.
7. Undulators "to be or not to be?" – to be presented
8. Cooling section and diagnostics.